

Performance tests of the SPIRAL2 LLRF system on a qualified accelerator cryomodule

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Abstract

CEA/Saclay has developed the LLRF system to control the accelerator cavities of the SPIRAL2^[1] project. This LLRF system, based on **in-house developed VME64X electronic boards**, has been designed in order to offer the high flexibility required by the various types of cavities (RFQ, normal conducting rebunchers and superconducting resonators), as well as the various operating modes of the accelerator.

A prototype system was manufactured in 2009 and intensively tested with a superconducting resonator in the beginning of 2010, in particular to demonstrate the possibility to operate the SPIRAL2 high Q ($\sim 10^6$) resonators using the **I/Q driven mode**, especially at cavity startup.

Since then, the LLRF series productions have been launched and completed, while the SPIRAL2 series cryomodules were assembled and qualified.

This poster presents the **performance characterization of the LLRF obtained with the final system** on a low beta ($\beta=0.07$) SPIRAL2 cryomodule of the series, during its qualification at Supratech-Cryo/HF facility at CEA/Saclay in september 2013.

All the data presented in this poster were taken **at the planned maximum operation cavity field of 6.5 MV/m**, but with a class-C power amplifier, different from the final class-AB amplifiers still under production.

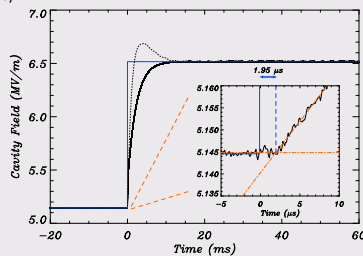
Specifications

- **88.0525 MHz** accelerator frequency
- **CW RF operation**, except for the RFQ in special commissioning modes.
- Stability of $\pm 1\%$ in amplitude, $\pm 0.8^\circ$ in phase (LLRF allocated budget only)
- **Common hardware** to control the **four types of cavities** including the RFQ driven by 4 power amplifiers
- Measure of the cavity detuning for the cavity frequency control
- Conditioning features
- **Protection** of the supraconducting cavity **power couplers**
- Automatic startup of the cavities
- EPICS drivers for the control-command.

Useful LLRF tools to adjust the loop parameters^[4]

The LLRF FPGA and associated EPICS control software offer a number of useful tools to optimize the loops:

- **High capacity (256 MB)**, **high resolution circular buffer** (sampling period down to 14 ns) with decimation capability, to store all digital data.
- Capture of software-triggered **transient responses** in data files.
- Generation of **RF perturbations with a programmable frequency**, used to determine the perturbation rejection versus frequency.



Example of transient responses captured in the memory buffer. This allows to optimize the transient response, as well as to measure the system latency.

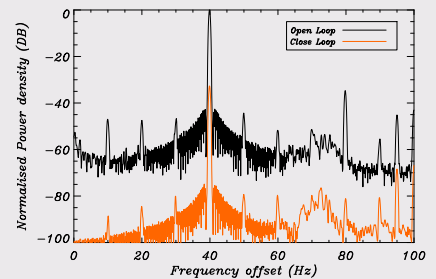
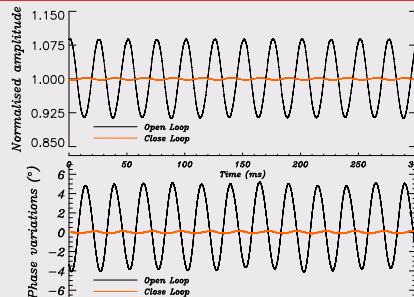
For the optimization of the system, the PI parameters of the loops were adjusted to avoid any overshoot like the one showed in dotted line. Indeed, there are uncertainties about the capability of the power amplifier, still under production, to tolerate overshoots. This results in a loss of LLRF performance, but it is still acceptable as far as the specifications are concerned.

The LLRF system itself contribution to the measured latency of 1.95 μ s is about 95 ns (see ref [4]), and the difference with respect to the measured value of 1.95 μ s is due to the addition of several propagation delays due to cavity coupling, power amplifier, circulator and cables.

Loop gain determination

To assess the loop performance, an artificial perturbation at any frequency in the range [0-150 kHz] can be injected in the cavity field thanks to the FPGA feature shown in [4].

The example shows temporal and spectral views of the rejection of the perturbation at 40 Hz, which is close to the highest microphonics. In this case, the gain is about 33 dB.

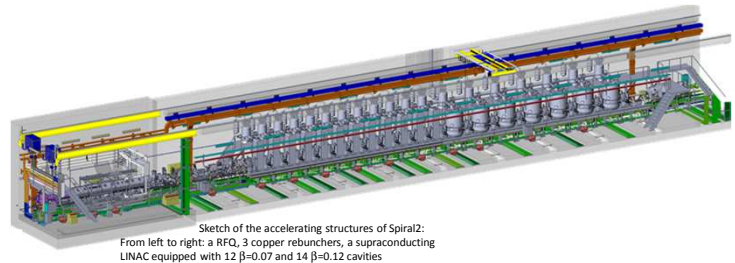
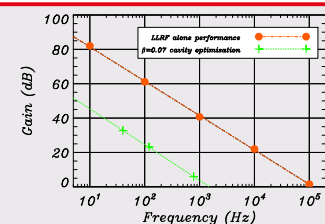


Conclusion

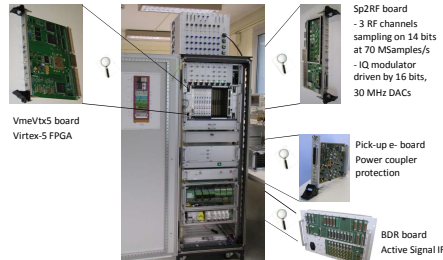
As far as it could be tested, the **spiral2 LLRF exceeds the performance required by the beam dynamics**, even if the Spiral2 power amplifier could not handle transient overshoots.

The next steps will be the adjustment of loop parameters with

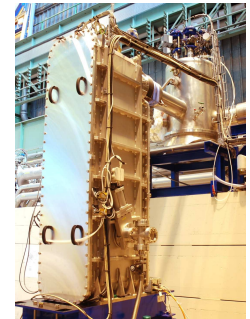
- the final power amplifiers,
- the final cryogenic environment
- last but not least, with the beam, expected at the **end of 2014**.



Sketch of the accelerating structures of Spiral2:
From left to right: a RFQ, 3 copper rebunchers, a supraconducting LINAC equipped with 12 $\beta=0.07$ and 14 $\beta=0.12$ cavities

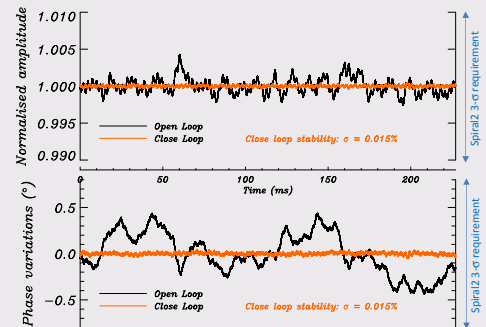


View of one of the 5 LLRF racks. The core is a VME-64X chassis equipped with in-house developed electronic boards, controlling up to 8 cavities^{[2],[3]}



View of a $\beta=0.07$ A cryomodule on the cryogenic test stand at CEA/Saclay

Results



Short-term comparison in open and close loop of the cavity voltage at the nominal maximum set point of 6.5 MV/m, without artificial perturbations.

Close Loop stability: $\pm 0.045\%$, $\pm 0.045^\circ$.

The open loop signal is already within specifications, because the cryogenic environment of the Saclay test stand is very stable. In order to reliably assess the close loop performance, the injection of artificial perturbations is needed (see below).

Nota Bene : The stability has been checked by a second acquisition system, completely independent from the LLRF system doing the control of the cavity, only sharing the reference frequency for synchronization.

References

- [1] R. Ferdinand et al. "Process of construction and installation of the Spiral2 accelerator", Ipac 2013, Shanghai, China, May 2013
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- [3] Y. Mariette et al. FPGA architecture for the Spiral2 digital low level RF, 17-20 October 2001, DESY - Hamburg, Germany
- [4] S. Sube et al., this conference.